THE PHYSICS OF FLIGHT

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Chapter V - Propeller Forces

Energy management is extremely important in all facets of flying. From the full-power setting required for take-off to the low-power flight at landing, proper energy management is critical to smooth flight. Consider the aerobatic pilot and the exotic maneuvers with which he graces the sky. The pilot is continually increasing and decreasing power settings so both potential and kinetic energy are available when needed.

We have a tendency to think of the engine and propeller as the sole source of power and airspeed. That is not always correct as we can trade altitude for airspeed, which can accumulate and provide the energy needed for maneuvers. Watch some of the aerobatic pilots perform dead-stick and you can quickly see how this works. Unfortunately, it requires a lot of altitude to generate the airspeed and energy needed even for fairly basic maneuvers.

For the moment, let's concentrate on the propeller. Just how does the prop move the plane? The propeller blades produce lift in the same way the wings do – moving an airfoil through the air to produce lift. When that lift acts in a forward direction it is called thrust. You may recall that thrust is one of the four forces that act on a airplane in flight (lift, weight, thrust, and drag). When thrust is available in a sufficient amount, the plane is moved forward. The faster the propeller turns, the faster the rate of air flow, and the more thrust is generated.

Most of the time when flying, this is about all you need to know about the forces the propeller generates. However, at low power settings the propeller generates other forces that can be useful in some aerobatic maneuvers, but as other times can be fatal to your airplane. Some of those forces include P-factor, torque, slipstream, and precession.

Remember playing with gyroscopes when you were a kid? OK, maybe you are like me and still enjoy playing with gyroscopes! When that toy is spinning fast and you try to turn it, it won't go the direction you want. If you paid attention, you noticed that it moved 90 degrees further on in the direction of rotation. Any helicopter pilot understands this, since it is critical to how the rotor head behaves. The propeller on the airplane also is a gyroscope of sorts. Turning the plane to the right results in a downward push on the propeller. A quick increase in pitch attitude results in a tendency to turn right. Confused? Get a gyroscope and play with it. Turn it so it is spinning in the same direction as a propeller, and try changing positions as the propeller on your airplane would during flight maneuvers. Additionally, when moving the plane at slow airspeeds there is little air movement on the control surfaces to stabilize the effects of the gyroscopic forces. In slow flight you need much more rudder and elevator control to keep the airplane pointed in the desired direction.

As the air from the propeller corkscrews back across the airplane, slipstreaming occurs. At higher airspeeds, this spiraling stream of air hardly touches the fuselage, but at slower speeds it exerts most of its force against the left side of the fuselage. It acts on the left side because of the clockwise rotation direction of the propeller (as viewed from the cockpit), since the wings and fuselage block the slipstream from acting on the right side. This is most notable during the take-off run and during slow flight, and has to be countered by application of right rudder.

Torque is much simpler to understand. The propeller spins in a clockwise direction, which has a tendency to turn the airplane in a counterclockwise direction. In full-scale airplanes, the design compensates for this tendency when at cruising speeds, but at lower speeds the airplane will have a tendency to roll to the left. You can compensate for this effect by using ailerons to balance the torque forces. When deflecting the ailerons at slow speeds, the differential drag between the two wings will require the application of rudder to maintain a straight course.

Probably the most debated propeller force is called P-factor. There are few pilots who have explored the physics of flight that have managed to avoid discussions about how this force is generated and how it acts on the airplane. Even those who have chosen aeronautical engineering as a profession can't always agree on the subtleties of this force.

We already discussed that a propeller acts like a wing in the generation of lift. As the angle of attack increases, more lift is generated. Consider once again that the propeller spins in a clockwise direction when viewed from the cockpit. When the plane is climbing, the descending blade (on the right side of the plane) has a greater angle of attack than the blade on the left side. You may want to get one of your airplanes to see how this works. Turn the propeller so it is horizontal, and then look at the difference in angle of attack between the blades as the airplane is pitched up. Notice that when the plane climbs, the blade on the right side has a greater angle of attack and will generate more lift than the left blade. The additional thrust from the right blade has a tendency to turn the airplane to the left. This tendency is called P-factor, and can be countered at low airspeeds with the generous application of right rudder.

This brief discussion of propeller forces should help you understand why rudder is needed at slow airspeeds and high power settings. Also, it should begin to help you understand some of the forces that are used for aerobatic maneuvers, and why it is easier to do those maneuvers in one direction versus the other.